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The effect of location class category and pipe wall thickness on risk level onshore pipeline oil

Zakki Fuadi Emzain*, **Makhmudul Fikri**, **Satworo Adiwidodo**, **Ratna Monasari**, **Talifatim Machfuroh**
Mechanical Engineering Department, Politeknik Negeri Malang, Malang, 65141, Indonesia
*Corresponding author: zfemzain@polinema.ac.id

Abstract

Pipelines are essential infrastructure for efficient oil and gas production operation, necessitating their continuous and reliable functionality in all locations and circumstances. Nevertheless, the pipeline can fail during operation due to multiple detrimental variables. This study evaluated the impact of the location classification category and pipe wall thickness on the risk level of onshore pipelines. The risk assessment method employed was a semi-quantitative approach derived from the reference "Pipeline Risk Management Manual" by W. Kent Muhlbauer. The distributing crude oil pipeline, which spans a distance of 18 kilometers and has a diameter of 6 inches, was evaluated. The evaluation yielded a pipeline relative risk score of 0.91, classifying the pipeline as belonging to risk category 1B. Following this, the assessment findings were analyzed for all 36 pipeline segments, classifying 26 segments in the 1B category and the remaining 10 segments in the 2B category. From the analysis results, the difference between the two risk categories was produced by differences in location class categories, where the pipeline segment in location class 1 creates a 1B risk category; meanwhile, class 3 produces a 2B risk category. Furthermore, a pipeline with a wall thickness of 5.156 inches is associated with a risk score of 0.81, but a wall thickness of 4.1 inches yields a score of 1.41. These results indicate that the location class category and pipe wall thickness significantly impact the risk of onshore pipelines.

Keywords:
Location class category, Muhlbauer method, onshore pipeline, risk assessment.

1 Introduction

Indonesia possesses large reserves of oil and gas, which serve as crucial sources of energy to fulfill the daily energy requirements of its population [1]. The national crude oil output in 2018 reached 808,000 Barrels Per Day (BPD), while the consumption stood at 1,785,000 bpd [2]. Most oil exploration, processing, and distribution activities in different territorial areas are carried out through several pipelines [3]. Due to its extensive reach, safety, reliability, and cost-effectiveness, the pipeline is the predominant method for transporting hydrocarbons [4].

During the distribution process, the pipeline traverses public areas, including rural, urban, office, forest, and oceanic regions, exposing it to potential failures from many circumstances [5]. Like 31th of March, 2018 accident, an oil spill occurred in Balikpapan Bay. This accident was triggered by the rupture of the offshore pipeline connecting the Single Point Mooring (SPM) Terminal Lawe-lawe to CDU IV Pertamina RU V Balikpapan [6]. The oil spill caused extensive pollution in the Gulf, affecting hundreds of hectares. The incident in Indonesia was the most severe environmental catastrophe in the past ten years, destroying 600 hectares of mangroves and 18,000 hectares of bays [7]. Undeniably, it is certain that it will also affect human health, safety, and the environment [8]. The reputation of the affiliated company is also at risk since it will damage its positive image.

Several causes can potentially cause damage, two of which are the wide range of installation conditions that can pose mechanical and chemical hazards to the safety and integrity of the pipes. A significant aspect that poses a danger to the integrity of pipeline safety is the diversity of route conditions [9]. In addition to installation circumstances, the risk associated with pipelines is also affected by the thickness of the pipe wall. The pipe wall is crucial in withstanding pressure and preventing fluid leaks during distribution. Therefore, the important of managing the integrity of oil and gas pipelines through effective and sustainable risk assessment.

Multiple academics have completed their work on the risk assessment of onshore pipelines. Several studies employ quantitative methods to analyze pipeline characteristics. For instance, Lei Ma et al. utilized grid differences across pipeline sections [10], Young-Do Jo et al. focused on lethal length and its cumulative effects [11], and Peng Zhang et al. examined pipelines placed in a single ditch [12]. Z.Y. Han et al. undertook a comparative analysis of qualitative and quantitative risk assessment methodologies [13]. Linlin Lu and colleagues employed a hybrid approach, integrating a risk matrix with a bow-tie model [14]. However, the studies mentioned above primarily utilize qualitative methods and provide only one comparative analysis. Therefore, a comprehensive risk assessment study for onshore pipelines incorporating quantitative and qualitative methods has not been conducted thus far.

W. Kent Muhlbauer (2004) is an example of a pipeline integrity management approach incorporating past failure data into its risk assessment [15]. This technique offers the capability to evaluate both time-dependent and time-independent forms of damage. Furthermore, this approached incorporates multiple logical assessment criteria to evaluate probable chemical and mechanical damage at various levels [16]. Therefore, it facilitates the attainment of results that can be continuously enhanced. The method utilizes a semi-quantitative approach to represent pipeline risk management, resulting in a relative risk score as the end output.

This paper proposes a study on the assessment of risk pipelines using the W. Kent Muhlbauer approach. The risk results will serve as a criterion for assessing the impact of location class and pipe wall thickness on the onshore pipeline risk.

2 Materials and Methods

The data was obtained from the piping's design, construction, installation, and prior inspection data. The risk assessment process can be determined from the data. The subsequent information is utilized in the process of analysis. Table 1 displays the pipe specifications, while Table 2 offers the content test results conducted during the fluid process.

A series of stages were devised to facilitate prompting the intended target to perform a risk assessment. Fig. 1 depicts the sequential phases of this investigation. Every category of Probability of Failure (POF) evaluation variables has a maximum point index of 100, resulting in a total maximum score of 400 for the entire POF. Meanwhile, Consequence of Failure (COF) has an unlimited potential worth due to diverse assessment indices.

This study adopted a semi-quantitative approach integrating qualitative and quantitative components to understand phenomena better or investigate research inquiries. The approach entails gathering data in a quantitative format and conducting thorough analyses of different assessment aspects using the "Pipeline Risk Management Manual", pipe wall thickness, historical maintenance records, and installation procedures. This process yielded comprehensive assessment results and analysis outcomes. Subsequently, the evaluation generated a risk level. Appropriate mitigation activities will be provided if the risk level falls within the medium to high range. If the risk level is low, it is sufficient to ascertain the remaining lifespan of the maintenance program. This study assessed the possibility of pipe malfunction due to the influence of the location class category's thickness and the pipe wall's thickness owned by XYZ company from SP X - SPU Y along the 18 km with 36 segments. The semi-quantitative W. Kent Muhlbauer method was used to determine the risk assessment process.

Table 1. Pipe specification

Data	Units
Length (m)	18000
Total segment	36
Lenght persegment (m)	500
Type pipe	Seamless
Inside diameter (inch)	6.065
Outside diameter (inch)	6.625
NPS (inch)	6.00
Material grade	API 5L Gr.B
Nominal thickness (inch)	7.11
SMYS (psi)	35500
Construction type	AG (mostly)
Built year	2015

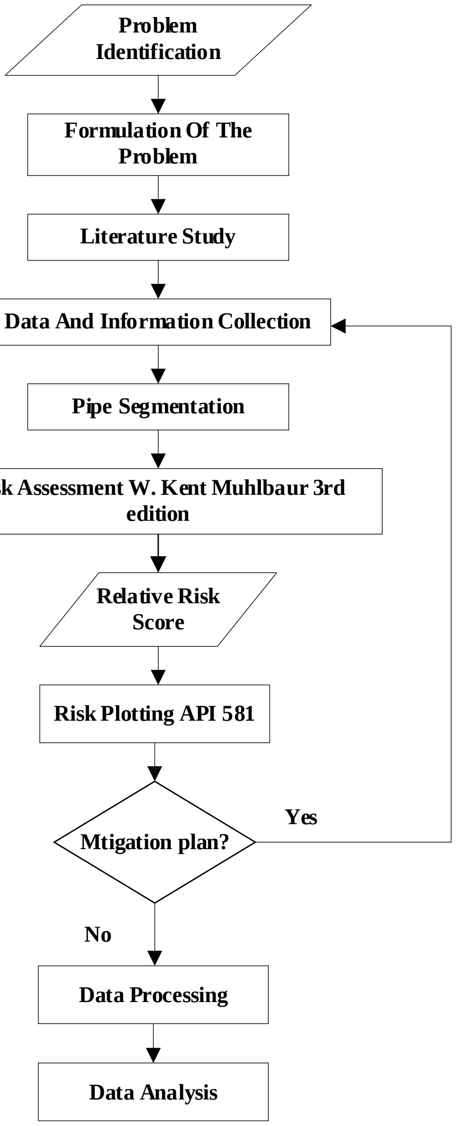


Fig. 1. Research flow chart.

Table 2. Content test results from the process of fluid

Produce water	Value
SRB	$<10^1$
CO_2 (mg/L)	51.05
Sulfide (mg/L)	0.07
Fe (mg/L)	1.07
Turbidity	79.38
Ph	7.3
DO (mg/L)	0.12

3 Results and Discussion

Based on the risk assessment method, the risk was obtained from calculating POF with Leak Impact Factor (LIF) from the cause of pipe process failure.

3.1 Probability of Failure (POF)

Probability of Failure (POF) is the possibility of equipment failure caused by single or multiple damage mechanisms that can damage the integrity of the equipment. The damage mechanism also varies, such as chemical and mechanical. From the results of the assessment that has been carried out, a table of probability of failure results obtained (Table 3).

Table 3. Third-party damage index recapitulation

	Third-party damage							
Assessment variable	Minimum depth cover	Activity level	Aboveground facilities	One call	Public education	ROW condition	Patrol frequency	Total score
Segment point (meter point)								
1	8	5	0	2	0	2	6	23
2	8	5	0	2	0	2	6	23
3	8	5	0	2	0	2	6	23
4	8	5	0	2	0	2	6	23
5	8	5	0	2	0	2	6	23
6	8	10	0	2	0	2	6	28
7	8	10	0	2	0	2	6	28
8	8	10	0	2	0	2	6	28
9	8	10	0	2	0	2	6	28
10	8	10	0	2	0	2	6	28
11	8	10	0	2	0	2	6	28
12	8	10	7	2	0	2	6	35
13	8	10	7	2	0	2	6	35
14	8	10	0	2	0	2	6	28
15	8	10	0	2	0	2	6	28
16	8	10	0	2	0	2	6	28
17	8	20	10	3	0	2	6	49
18	8	20	0	2	0	3	6	39
19	8	20	2	3	0	4	6	43
20	8	20	10	4	0	4	6	52
21	8	20	10	4	0	2	6	50
22	8	5	0	2	0	2	6	23
23	8	20	10	3	0	2	6	49
24	8	5	0	2	0	2	6	23
25	8	5	0	2	0	2	6	23
26	8	5	0	2	0	2	6	23
27	8	20	10	4	0	0	6	48
28	8	10	4	4	0	2	6	34
29	8	15	0	3	0	2	6	34
30	8	20	10	4	0	4	6	52
31	8	5	2	2	0	2	6	25
32	8	20	10	4	0	0	6	48
33	8	10	4	4	0	4	6	36
34	8	10	7	3	0	5	6	39
35	8	20	10	4	0	4	6	52
36	8	20	10	4	0	3	6	51

3.1.1 Third-Party Damage

The third-party damage index is a pipeline safety risk factor derived from the activities of personnel/parties unrelated to the pipeline [17]. Table 3 shows the third-party damage recapitulation data obtained.

3.1.2 Corrosion Index

This potential index comes from internal and external corrosion from the pipe itself. The triggers of each type of corrosion are very diverse; generally, the threat is very detrimental and must occur in pipes with steel material. Corrosion will reduce the pipe's integrity by thinning the wall thickness so that pipe leakage is possible over time, accompanied by a continuous production load. The corrosion index recapitulation data was obtained, as shown in Table 4.

Table 4. Corrosion index recapitulation

Variable assessment	Corrosion Ind.			
Segment point (meter point)	Atmospheric Corro.	Internal Corro.	Subsurface Corro.	Total score
1	7	20	23	50
2	7	20	23	50
3	7	20	23	50
4	7	20	23	50
5	7	20	23	50
6	7	20	23	50
7	7	20	23	50
8	7	20	23	50
9	7	20	23	50
10	7	20	23	50
11	7	20	23	50
12	7	20	23	50
13	7	20	23	50
14	7	20	23	50
15	7	20	23	50
16	7	20	23	50
17	7	20	31	58
18	7	20	31	58
19	7	20	31	58
20	7	20	31	58
21	7	20	31	58
22	7	20	23	50
23	7	20	23	50
24	7	20	23	50
25	7	20	23	50
26	7	20	23	50
27	7	20	23	50
28	10	20	23	53
29	7	20	23	50
30	7	20	23	50
31	7	20	23	50
32	7	20	23	50
33	7	20	40	67
34	10	20	40	70
35	7	20	40	67
36	7	20	40	67

3.1.3 Design Index

The design index assesses matters related to the effectiveness of pipe reliability when operating and various potential mechanical threats that can damage the pipeline's integrity. Table 5 shows the design index data obtained.

Table 5. Design index recapitulation

Variable assessment	Design index					
Segment point (meter point)	Safety factor	Fatigue	Surge potential	Integrity verification	Land movements	Total score
1	7	6	10	0	0	23
2	7	6	10	0	0	23
3	7	6	10	0	0	23
4	7	6	10	0	0	23
5	7	6	10	0	0	23
6	7	6	10	0	0	23
7	7	6	10	0	0	23
8	7	6	10	0	0	23
9	7	6	10	0	0	23
10	7	6	10	0	0	23
11	7	6	10	0	0	23
12	7	6	10	0	0	23
13	7	6	10	0	0	23
14	7	6	10	0	0	23
15	7	6	10	0	0	23
16	7	6	10	0	5	28
17	7	6	10	0	0	23
18	7	6	10	0	10	33
19	7	6	10	0	15	38
20	7	6	10	0	15	38
21	7	6	10	0	15	38
22	7	6	10	0	5	28
23	7	6	10	0	15	38
24	7	6	10	0	0	23
25	7	6	10	0	0	23
26	7	6	10	0	5	28
27	7	6	10	0	15	38
28	7	6	10	0	15	38
29	7	6	10	0	15	38
30	7	6	10	0	10	33
31	7	6	10	0	5	28
32	7	6	10	0	5	28
33	7	6	10	0	15	38
34	7	6	10	0	15	38
35	7	6	10	0	15	38
36	7	6	10	0	15	38

3.1.4 Incorrect Operations

Incorrect operations is an aspect of risk assessment that contains the causes of pipe failure due to pipe operating errors not by Standard Operational Procedures (SOP) [18]. Undeniably, many incidents in various places originate from operators who do not operate equipment carelessly. Table 6 shows incorrect operations data obtained.

From the results in Table 7, the total score index Probability of Failure (POF) from the onshore pipeline was 175.51.

3.2 Leak Impact Factor (LIF)

Leak Impact Factor (LIF) is a factor that considers several variable aspects of the impact caused to the safety of human lives and environmental pollution. The higher the LIF value generated, the higher the risk category owned by the pipeline. Fig. 2 is a diagram of pipeline risk from the LIF assessment [19].

Table 8 was the results of the Leak Impact Factor (LIF) assessment.

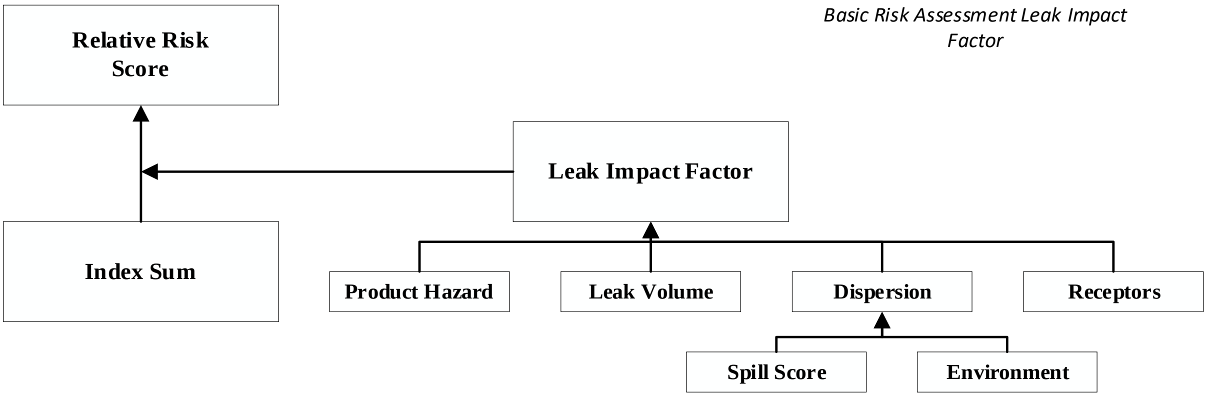


Fig. 2. Pipeline risk LIF assessment diagram.

Table 6. Incorrect operations recapitulation

	Variable assessment	Incorrect operations				
		Design	Construction	Operation	Maintenance	Total score
Segment point (meter point)	1	11	0	34	14	59
	2	11	0	34	14	59
	3	11	0	34	14	59
	4	11	0	34	14	59
	5	11	0	34	14	59
	6	11	0	34	14	59
	7	11	0	34	14	59
	8	11	0	34	14	59
	9	11	0	34	14	59
	10	11	0	34	14	59
	11	11	0	34	14	59
	12	11	0	34	14	59
	13	11	0	34	14	59
	14	11	0	34	14	59
	15	11	0	34	14	59
	16	11	0	34	14	59
	17	11	0	34	14	59
	18	11	0	34	14	59
	19	11	0	34	14	59
	20	11	0	34	14	59
	21	11	0	34	14	59
	22	11	0	34	14	59
	23	14	0	34	14	62
	24	11	0	34	14	59
	25	11	0	34	14	59
	26	11	0	34	14	59
	27	17	0	34	14	65
	28	17	0	34	14	65
	29	11	0	34	14	59
	30	11	0	34	14	59
	31	11	0	34	14	59
	32	11	0	34	14	59
	33	11	0	34	14	59
	34	14	0	34	14	62
	35	14	0	34	14	62
	36	14	0	34	14	62

Table 7. Overview of risk assessment results

Variable	Max.	POF	Failure %	Survive %	Category
Third-party damage	100	33.86	33.86	66.14	Safe
Corrosion index	100	53.16	53.16	46.84	Not safe
Design index	100	28.83	28.83	71.17	Safe
Incorrect operations	100	59.66	59.66	40.34	Not safe
Total	400	175.51	175.51	224.49	Safe

Table 8. Assessment Consequence of Failure (COF) results

Variabel assessment	Index
Product hazards	4
Leak Volume (LV)	4
Dispersion (D)	4
Receptors (R)	3
Index sum	192

3.3 Risk Evaluation

After the results of Probability of Failure (POF) and Consequence of Failure (COF) are generated, then calculate the data from both data using a formula reference based on literacy "Pipeline Risk Management Manual" 3rd edition – W. Kent Muhlbauer, so that the risk onshore pipeline is obtained [18]:

$$\begin{aligned} \text{Relative risk} &= \text{Index Sum} \div \text{LIF} \qquad (1) \\ &= 175 \div 192 \\ &= 0.91 \end{aligned}$$

From the Probability of Failure (POF) and Leak Impact Factor (LIF) assessments, the risk value was calculated using a risk plotting process using the API 581 Risk-Based Inspection risk matrix. It aims to be able to interpret the analyzed pipelines, including pipelines with low, medium, high medium, and high-risk levels. Fig. 3 were the results of the SP X - SPU Y 6-inch risk pipeline plotting [20].

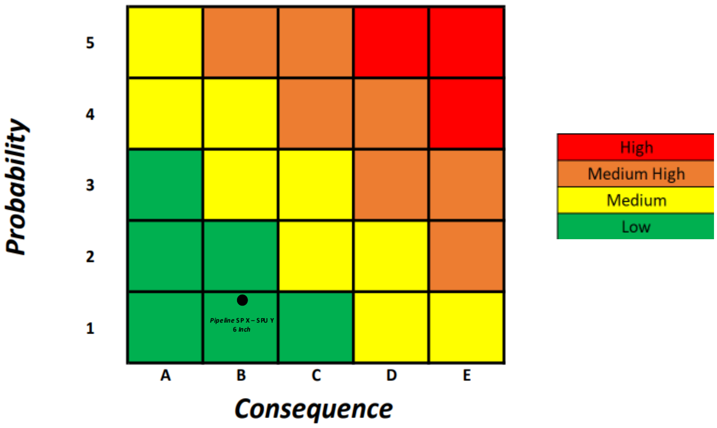
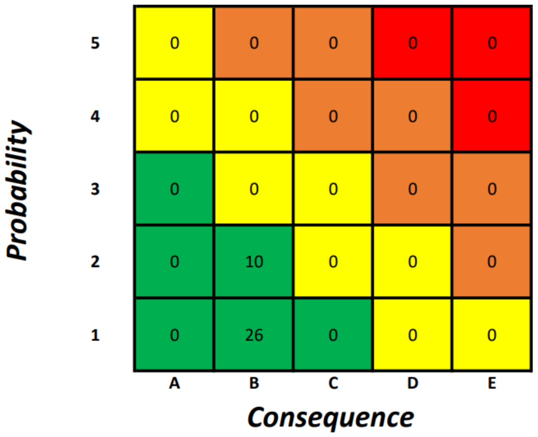


Fig. 3. Risk matrix onshore pipeline.

From the risk matrix image of the risk assessment results, it can be concluded that the SP X - SPU Y 6-inch pipeline is included in the low-risk category 1B. However, the risk assessment pipeline divided into 36 segments produces several levels of risk. To determine the pipeline per-segment risk assessment results, Fig. 4 were the results of interpreting the SP X - SPU Y 6-inch pipeline per-segment risk assessment.



	A	B	C	D	E
5	0	0	0	0	0
4	0	0	0	0	0
3	0	0	0	0	0
2	0	10	0	0	0
1	0	26	0	0	0

Fig. 4. Risk matrix result of the 36 pipe segment.

From the onshore pipeline risk matrix image, all 36 pipeline segments were obtained, and two categories were obtained, including 26 pipeline segments in the 1B category while the other 10 were in the 2B category. This category difference was influenced by the pipeline location class, where the ten pipelines were in the level 3 location class category. In addition, the factor of pipe wall thickness, which is thinner than other pipe wall thickness, causes these ten pipelines to have a relative risk score above 1. Therefore, the pipeline was classified in the risk 2B category.

3.4 The Effect of Location Class Categories on Pipeline Risk Levels

The effect of location class categories on pipeline risk levels can be analyzed from the graph as shown in Fig. 5.

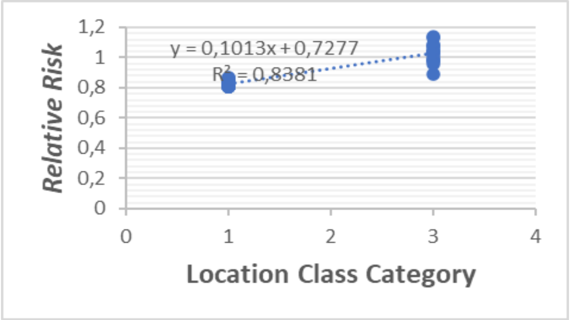


Fig. 5. Analysis graph of the effect of location class categories on risk levels.

Based on the graph in Fig. 5, it can be seen that the pipeline occupies a place classified as location class 1, then the relative risk obtained will be low (0.81). Furthermore, the higher the pipeline location class category 3, the greater the relative risk generated (1.141).

3.5 The Effect of Pipe Wall Thickness on Pipeline Risk Levels

The effect of pipe wall thickness on risk levels can be analyzed from the graph as shown in Fig. 6.

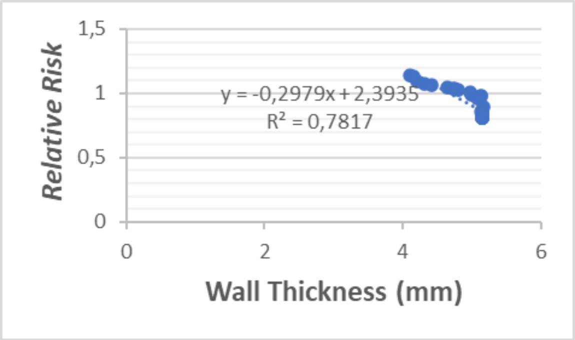


Fig. 6. Analysis graph of the effect of pipe wall thickness on risk levels.

Based on the graph in Fig. 6, it can be seen that the pipeline has a large pipe wall thickness (5.141 inches), then the relative risk obtained is low (0.81). Meanwhile, the thinner the thickness of the pipe wall (4.1 inches), the greater the relative risk produced (1.141).

4 Conclusion

The analysis and discussion undertaken in this study lead to the conclusion that location class 3 has the highest indication among other categories, with the lowest pipe wall thickness measuring 4.10 mm. As a result, the risk score reaches a peak of 1.14, even if the matrix remains in the low category. Therefore, it can be inferred that a higher pipeline location class and smaller wall thickness contribute to an elevated risk level of oil and gas pipelines.

Further research is anticipated to analyze the failure comprehensively using FMEA or FTA methodologies and cost estimations about the consequences of leaks and the expenses associated with oil pipeline integrity management.

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